

Radiologist variability in assessing the position of the cavo-atrial junction on chest X-rays

SHORT TITLE: CXR variability of CAJ position

MANUSCRIPT TYPE: Full paper

Chan, Tze Y¹, MBChB (Hons), FRCR

England, Andrew², PhD

Meredith, Sara M¹, MBChB, BMedSci

McWilliams, Richard G.¹, MB BCh, FRCR, EBIR

Department of Radiology¹

Royal Liverpool University Hospital NHS Trust

Prescot Street, Liverpool, L7 8XP, United Kingdom.

Directorate of Radiography²

University of Salford, Allerton Building, Frederick Road, Salford,

M6 6PU, Manchester, United Kingdom.

Telephone: +44161 295 0703; Fax number: +441612957000

Email: a.England@salford.ac.uk (corresponding author).

Funding source: none

Conflicts of interest: none

Radiologist variability in assessing the position of the cavo-atrial junction on chest radiographs

SHORT TITLE: CXR variability of CAJ position

Abstract

Objectives: To assess the variability in identifying the cavo-atrial junction (CAJ) on chest x-rays amongst radiologists.

Methods: Twenty-three radiologists (13 consultants and 10 trainees) assessed 25 postero-anterior erect chest x-rays (including eight duplicates) and marked the positions of the CAJ. Differences in the CAJ position both within and between observers were evaluated and reported as limits of agreement, repeatability coefficients, intra-class correlation coefficients and displayed graphically with Bland-Altman plots.

Results: The mean difference for *within* observer assessments was -0.2 cm (95% limits of agreement, -1.5 to +1.1 cm) and *between* observers was -0.3 cm (95% limits of agreement, -2.5 to +1.8 cm). Intra-observer repeatability coefficients (RC) were marginally lower for consultants when compared to trainees (1.1 versus 1.5). RCs between observers were comparable (2.1 versus 2.2) for consultants and trainees, respectively.

Conclusions: This study detected a large inter-observer variability of the CAJ position (up to 4.3 cm). This is a significant finding considering that the length of the SVC is reported to be approximately 7cm. We conclude that there is poor consensus regarding the CAJ position amongst radiologists.

Advances in knowledge: No comparisons exist between radiologists in determining CAJ position from chest X-rays. This report provides evidence of the large observer variability amongst radiologists and adds to the discussion regarding the use of chest X-rays in validating catheter tip location systems.

KEYWORDS: variability; catheter position; radiologist; chest x-ray; positioning system.

Introduction

Peripherally inserted central catheters (PICCs) are frequently being used for long-term venous access to administer drugs such as antibiotics(1)and chemotherapy(2), as well as for the delivery of total parenteral nutrition (3). PICCs are often left in position for several weeks or months; it is therefore vital that the catheter tip is sited in an optimum position within the central circulation (4, 5). Techniques are available which can help reduce the incidence of catheter tip malposition, including X-ray fluoroscopy (4-7). Fluoroscopy has limitations; it is an expensive resource (8, 9), has risks from the use of ionising radiation (9) and is impractical for critically ill patients (5). A newer and more popular alternative to fluoroscopic guidance is the use of electro-magnetic tracking and intra-cavity ECG (6, 10).

The successful introduction of catheter tip positioning systems within clinical practice has relied on validation against a 'gold standard', a post-insertion chest X-ray. Reports of technical success do vary, in a report by Johnston et al., catheter malposition rates, defined using a post-insertion chest X-ray, have been reported (5). When an adequate position was defined as low superior vena cava or cavo-atrial junction (CAJ), 134 catheters (56.1%; 95% CI 50-62%) were malpositioned. A separate study by Lelkes et al., reported more favourable outcomes where 375 of 384 patients (97.7%) had the catheter tip positioned appropriately, again this was defined by post-insertion chest X-ray (7).

Validation of catheter tip positioning systems using chest X-ray is in our opinion problematic. It is widely speculated that assessment of catheter tip position on chest X-ray is inaccurate and subject to inter-observer variability (11-15). For chest X-ray to be a validated tool would require the radiologist to be able to reliably identify the CAJ position. To our knowledge the accuracy of this task, in this specifically trained group, has not been assessed. The aim of our study was to assess intra- and inter-observer variability in identifying the cavo-atrial junction (CAJ) using adult chest X-rays.

Materials and Methods

Radiologists (consultants and trainees) from a single University hospital were invited to take part in this study. Recruitment was aimed at participants with general radiology experience

1 and those with a specific interest in chest radiology were asked not to take part. Thirteen
2 radiology consultants and ten trainees volunteered. Seventeen randomly selected postero-
3 anterior (PA) chest radiographs were collected from a picture archiving and communication
4 system. All images had been previously acquired as part of an anonymised teaching archive
5 and therefore no formal ethical approval was sought. The chest X-rays were labelled with
6 numbers 1 to 17. Eight of these seventeen chest X-rays were randomly selected and
7 duplicated. These images were then subsequently labelled as images 18 to 25 and had
8 deliberate alterations to the shuttering borders and image annotations in order to reduce
9 the chances of the duplicate images being detected by the observers. The decision
10 regarding the number of images was based on the need to assess intra- and inter-observer
11 variability and the estimated time required by the observers to complete the task. The
12 sample size used in this study was consistent with those used in similar studies reported in
13 the literature (12, 16). All chest X-rays were acquired to a standard technique (17) and
14 acceptable image quality was verified by two of the study authors.

25 Each participant was asked to retrospectively indicate the position of the CAJ on
26 each of the 25 chest X-rays images, independently, using a hospital laptop. The laptop,
27 usually used by on-call radiologists to report scans remotely, had a 1920 x 1200 pixel 17 inch
28 screen running Microsoft Powerpoint 2007 (Microsoft Corp, Redmond, Washington). It was
29 considered that the reporting laptop provided acceptable image quality for the purposes of
30 this research. All images were checked for quality on the laptop by two study authors. Also
31 if any participant felt that there were image quality issues which prohibited identification of
32 the CAJ position, then they could move on to the next image. Furthermore, the laptop also
33 conformed to the Royal College of Radiologists minimum specification for primary
34 diagnostic display devices used for clinical image interpretation (18).

35 Each of the radiologists were given basic instructions regarding the study and asked
36 to place an arrow at where they thought the position of the CAJ was in the cranio-caudal
37 plane (**Figure 1**). A research assistant was present at all times during the assessment in
38 order to ensure each radiologist understood the instructions and that the viewing
39 conditions remained consistent. After annotating each image with an arrow the image was
40 saved and the observer then moved on to the next image. Participants were not permitted
41

to make changes to the windowing or magnification settings nor adjust the image post-processing parameters.

Following data collection from all 23 radiologists, the annotated images were analysed by a study researcher. A horizontal line was placed on each image to provide a horizontal reference point on the image which was in a superior position to the CAJ. The horizontal reference point selected was the superior border of the aortic arch and remained in a fixed position on each of the 17 original images. The vertical distance from the tip of the observer placed arrow to the horizontal reference line (aortic arch) was measured on each chest X-ray. On each chest X-ray images there was a 10 cm scale on the right side of the image. This allowed the distance between the horizontal reference line and the tip of the manually placed arrow to be correctly calibrated. Calibration was based on distances at the image receptor surface.

Measurements between the observers annotations (arrows) and the horizontal reference line were undertaken using 400% magnification, this was selected to minimise any measurement errors. Each measurement was then repeated three times by the same study researcher and the mean value recorded. Measurements were then entered into a Microsoft Excel (Microsoft Corp, Redmond, Washington) spreadsheet. Measurements (calibrated) were compared to repeat measurements by the same observer and then repeat measurements between observers. Full details of the measurement and calibration processes are illustrated in **Figure 2**.

Statistical analysis

Several methods have been proposed for the evaluation of observer variability data. It is believed by many authors (15, 19) that for the analysis of measurement studies it is desirable to report the degree of agreement using multiple statistical methods as no method is perfect and each has its own limitations. First, the method described by Bland and Altman (20) was used to assess the intra- and inter-observer variability of CAJ position assessments. For the assessment of intra-observer variability the difference in position between each of the eight paired images by the same observer was calculated (1st CAJ assessment minus the 2nd CAJ assessment). Using these data the mean difference (between

the repeat CAJ positions) and standard deviation (SD) were calculated, as well as the 95% limits of agreement (LOA). LOA are a simple method of estimating the agreement interval within which 95% of the differences of the second measurement when compared to the first would fall. For inter-observer variability, the mean difference together with the LOA were calculated in a similar manner compared to the first observer (observer one) but excluding the eight repeated images.

Coefficients of Repeatability (RC) were calculated for the intra- and inter-observer variability. The RC, as defined by Bland and Altman (21), is based on the one-way analysis of variance with the subject as the factor and provides a measure of precision that represents the value below which the absolute difference between repeat measurements is expected to lie with a 95% probability after extracting biologic variability. To calculate RC, firstly the within subject variance(s_w^2) is calculated. Two CAJ identifications by the same/different observers will then be within $1.96\sqrt{2s_w}$ or $2.77s_w$ for 95% of the participants and this is the resultant RC value.

Intra-class correlation coefficients (ICC) were also used to report the degree of agreement within and between observers. A number of different models can be used for computing the ICC value (22). In this study, to report the observer variability, a two-way random model (23) was used since the set of images is a random subset of images from the class of chest radiographs and the radiologists were also randomly selected from the population of radiologists. Different guidelines exist for the interpretation of ICC: it has been suggested that an ICC value of less than 0.40 indicates poor reproducibility, ICC values in the region of 0.40 to 0.75 indicate fair to good reproducibility, and an ICC value of greater than 0.75 shows excellent reproducibility (24).

Results

A total of 184 paired images (23 observers; 8 duplicate observations) were assessed for intra-observer variability and the CAJ position was indicated on each of these images using a horizontal arrow. When comparing intra-observer variability for all observers the mean difference in CAJ position was -0.2 cm, 95% LOA [-1.5, +1.1] cm. Twenty-six (14%) intra-observer paired differences were > 1.0 cm. A more detailed analysis of intra-observer

variability is presented in **Table 1, Figures 3 & 4** together with a breakdown by observer type (consultant versus trainee).

For the assessment of inter-observer variability, a total of 391 images (23 observers; 17 observations) were assessed and the CAJ position was indicated on each of the images. When comparing CAJ positions between all observers, the mean (inter-observer) difference was -0.3 cm, 95% LOA [-2.5, +1.8] cm. A total of 124 (33%) paired differences were > 1.0 cm. A more detailed analysis of inter-observer variability is presented in **Table 2 & Figure 5**, including analysis between observer types. Upon review of **Figure 5** there was some linearity for paired differences between consultants and a distinct small cluster of paired differences above the upper LOA for trainees. The linearity could be explained by more senior observers identifying the CAJ as an area on the image and a not a finite point whereas the small cluster could represent a small number of more novice trainees.

The variability within observers (intra-) and the between observer variability (inter-) was further assessed using an intra-class correlation coefficient (ICC). Overall, the mean ICC for the overall cohort was 0.901 (95%CI 0.849 to 0.927) and 0.347 (95%CI 0.200 to 0.467) for intra- and inter-observer variability, respectively. Different guidelines exist for the interpretation of ICC: it has been suggested that an ICC value of less than 0.40 indicates poor reproducibility, ICC values in the region of 0.40-0.75 indicate fair to good reproducibility, and an ICC value of greater than 0.75 shows excellent reproducibility (24). The ICC values across the different observer types are displayed in **Table 3**.

Measurement differences in CAJ position were based on adjustment for magnification at the image receptor surface. The CAJ is not in direct contact with the image receptor and will, therefore, be subject to radiographic magnification. As a result, measurement differences between and within observers are likely to be influenced by the degree of magnification (CAJ to image receptor distance). Radiographic magnification (RM) can be quantified using the following equation:-

$$RM = \frac{\text{Source to Image Receptor Distance}}{\text{Source to Image Receptor Distance} - \text{CAJ to image receptor distance}} \quad (25)$$

Depending on distance between the CAJ and the image receptor surface, measurements would need to be adjusted for magnification.

Discussion

Catheter tip location systems are now available and are able to provide an indication of CVC tip position. In order to compare the results of catheter tip location systems a reference standard must be available. In recent studies electromagnetic detection systems have been compared against chest radiography (7, 26). However, in recent years several authors have questioned the value of a chest X-ray in defining tip position, arguing that for chest X-ray images to be an acceptable standard they would need to be consistent and accurate in identifying tip position (27, 28). Studies have shown that there can be constant disagreement as to the ideal position of a CVC on chest X-ray (9, 14). There is, however, some consensus that CVC tips should be located at the CAJ (32).

For the CAJ to be a sound reference point would require that this anatomical landmark can be repeatedly and consistently identified from chest X-rays. According to the work by Aslamy *et al.*, (30) the CAJ is defined as the caudal margin of the SVC at the level below which the SVC flares into the right atrial chamber. Radiographically, the CAJ has often been considered to be the right superior heart border in the plane of the SVC as an approximation (31). The report by Aslamy *et al.*, correlated radiographic landmarks with MRI scans and demonstrated that the right superior border of the heart on a chest X-ray is composed of the left, rather than the right, atrium in 38% of patients (30). From this they and others have argued that the cardiac silhouette on a chest X-ray in the region of the SVC is an unreliable indicator of CAJ (30, 32).

To our knowledge, our study is the first report on the variability of the CAJ position assessed by radiologists using chest X-rays. When comparing repeat measurements by the same observer (within-subject), 95% of CAJ positions were within 2.6 cm of each other.

Variation was marginally smaller for consultant radiologists when compared with trainees. This feature was also experienced in the study by Wirsing *et al.*, (14) who compared senior and junior radiologists in determining CVC tip malposition. For the study group as a whole, over three-quarters of within-subject CAJ position assessments were less than 1 cm apart. This suggests that observers are consistent when invited to undertake repeat assessments of CAJ position. Results are likely to reflect an individuals' consistency in applying internal definitions when asked to provide an opinion on the CAJ position on chest X-rays.

When comparing the determination of CAJ position between observers the agreement was lower. For the cohort as a whole, 95% of paired CAJ assessments were within 4.3 cm of each other. This equated to around 2/3 of paired assessments being within 1 cm or less of each other. Comparison between observer types also demonstrated that more senior observers were marginally more consistent in their assessment of CAJ position. On the whole there was a higher disagreement in the assessment of CAJ position between observers and this may be due to a lack of accepted radiological landmarks and definitions within the radiological community.

Intra-class correlation coefficients (ICC) can provide a useful tool for assessment of observer variability. Within our study ICC values for the assessment of intra-observer variability were above 0.88 and based on Rosner's work this can be interpreted as excellent reproducibility (24). When interpreting ICC values there was some evidence of intra-observer differences when separating consultants from trainees (ICC 0.92 versus 0.88, respectively). Both groups can, however, be categorised as excellent for intra-observer variability. For assessments between observers then the ICC values were lower, the group as a whole generated an ICC value of 0.35 which can be classified as poor agreement (24). There was little difference between consultants and trainees (ICC 0.36 and 0.35, respectively). ICC values are limited in that they are coefficients and do not provide information regarding whether any agreement or disagreement is clinically acceptable.

It has been observed that between 20 and 47% of CVCs are incorrectly classified to be in an intra-atrial position (30). Aslamy and colleagues, in a report in 1998, suggested that the effects of parallax and variations in radiographic technique may lead to erroneous

1 reporting of malposition (30). An additional factor that may have contributed to this figure
2 is the lack of agreement regarding the radiological landmarks for the CAJ. Our study goes
3 some way in proving that there is a lack of accepted landmarks between radiologists for
4 identifying the CAJ. Even with standardisation, based on Aslamy et al., a chest X-ray is
5 unlikely to be insufficient for allowing the precise identification of CAJ position. Other
6 methods such as transoesophageal echocardiography (TOE) are likely to be superior.
7 Confirming this, in a recent study comparing TOE to chest X-ray, the sensitivity and
8 specificity for chest X-ray, in determining catheter malpositioning, was 47% and 66%,
9 respectively (14). However, the use of TOE to replace chest X-ray in determining catheter
10 malpositioning for all central venous catheter placements will have significant resource
11 implications, is not practical and would be unpopular with patients.
12
13
14
15
16
17
18
19
20
21
22

23 When reporting this study we accept that there are limitations. Both radiographic
24 technique and parallax are likely to affect an observer's the ability to localise the CAJ. The
25 adequacy of chest X-ray images included in this study was determined by two co-authors.
26 Measurement variability may have been different if a wider range of chest X-rays was
27 included. A further limitation of this study was the lack of a definitive indicator of actual CAJ
28 position. One option was to use CT images and generate a RaySum style chest X-ray image
29 (33) from which observers could locate the CAJ. This was not considered to be a viable
30 option since there are large differences in image quality between a conventional chest X-ray
31 and those generated from CT data. In addition, CT images are almost always generated in
32 the supine position with arms raised above the head. This is a totally different position to
33 that of a typical chest X-ray and the resultant differences in apparent CAJ position would
34 need to be quantified.
35
36
37
38
39
40
41
42
43
44
45
46

47 Radiologists were invited to participate from a single UK hospital. Participation was
48 voluntary following an email invitation, this may have introduced some bias in that
49 radiologists who had concerns regarding their ability to precisely identify the CAJ may not
50 have opted to take part. As such the true variability CAJ assessments could be greater than
51 reported. We feel do, however, feel that this is unlikely to be a factor since observer
52 assessments were anonymised from the outset and recruitment was not an issue.
53 Observations were also undertaken on a hospital laptop and not on a typical reporting grade
54
55
56
57
58
59
60
61
62
63
64
65

PACS workstation. This is again unlikely to be significant as the laptop was used in image interpretation, images were checked for both anatomical content and quality and the laptop specification met national standards (18).

Radiographic magnification is also a consideration when interpreting measurement differences. Digital radiographs have scales located on the image which provides an indication of distance measurements calibrated to those on the surface of the image receptor. The CAJ sits within the thorax and will be a distance away from the image receptor surface and will, therefore, be subject to magnification. By way of an example a 2.0 cm^2 region at a postero-anterior tissue depth of 4 cm would cast a 2.1 cm^2 area on the resultant radiograph. At a depth of 8 cm this would increase to 2.2 cm^2 and as such the CAJ will not be a finite point on a chest x-ray but will correspond to an area, the size of which will depend on the distance away from the image receptor.

Based on results from this study there is a need for further work. One option is the role of training in reducing observer variability. Within our study we purposefully opted not to provide any training on the identification of CAJ position as we sought to capture the current levels of variability. We accept that it would be useful to ascertain the performance of assessing CAJ position following a period of training. In order to achieve this, it is important to gain a consensus on the radiological landmarks which promote accurate delineation of the CAJ position.

Conclusion

Accurate assessment of CVC tip position is essential in order to ensure adequate line function together with long-term patient safety. The limitations of chest radiography, in providing precise tip position, have been previously identified. This problem is further exacerbated by a lack of consistency amongst trained radiologists in the localisation of the CAJ. Currently, the consensus between radiologists is that the CAJ position sits within a 4.3 cm cranio-caudal region within the mediastinum. This is a significant finding considering that the length of the SVC is reported to be approximately 7cm.

LEGENDS FOR FIGURES

Figure 1. Postero-anterior chest X-ray image illustrating an example of an observer annotating the cranio-caudal position of the CAJ using an arrow tip (white arrow). The 10 cm vertical scale used in the calibration is present on the right side of the image.

Figure 2. Graphical illustration of the measurement and calibration processes. Using the calibration scale on the right of the image 10 cm radiographically equates to 6 cm on the image. The calibration factor ($10.0 \text{ cm} / 6.0 \text{ cm}$) equals 1.67 and is used to convert the 4.3 cm (aortic arch) to radiologist applied CAJ marker to its respective radiographic distance ($4.3 \text{ cm} \times 1.67 = 7.2 \text{ cm}$). As a result, in this example, the radiologist has indicated that the CAJ is 7.2 cm inferior to the superior border of the aortic arch.

Figure 3. Box and whisker plot providing an illustration of the median, inter-quartile range and minimum and maximum difference for assigned CAJ positions between observer groups for Image 1.

Figure 4. Intra-observer variability of CAJ identification on chest X-rays for both consultant radiologists and trainees. Intra-observer variability refers to the differences between repeat CAJ positions by the same observer (within observer). The difference between the two positions has been plotted against the mean distance in the CAJ position from the horizontal reference line. SD, standard deviation.

Figure 5. Inter-observer variability of CAJ identification on chest X-rays for both consultant radiologists and trainees. Inter-observer variability refers to the differences in CAJ position between multiple observers. These differences are plotted against the mean of the two CAJ

positions relative to the horizontal reference line. All calculations for inter-observer
variability were based on the CAJ positions by observer 1. SD, standard deviation.

References

1. Islam S, Loewenthal MR, Hoffman GR. Use of peripherally inserted central catheters in the management of recalcitrant maxillofacial infection. *J Oral Maxillofac Surg* 2008;66(2):330-5.
2. Pittruti M, Emoli A, Porta P, Marche B, DeAngelis R, Scoppettuolo G. A prospective, randomized comparison of three different types of valved and non-valved peripherally inserted central catheters. *J Vasc Access* 2014;15(6):519-23.
3. Loughran SC, Borzatta M. Peripherally inserted central catheters: a report of 2506 catheter days. *J Parenter Enteral Nutr* 1995;19(2):133-6.
4. Amerasekera SS, Jones CM, Patel R, Cleasby MJ. Imaging of the complications of peripherally inserted central venous catheters. *Clinical radiology*. 2009;64(8):832-40. Epub 2009/07/11.
5. Johnston AJ, Holder A, Bishop SM, See TC, Streater CT. Evaluation of the Sherlock 3CG Tip Confirmation System on peripherally inserted central catheter malposition rates. *Anaesthesia*. 2014;69(12):1322-30. Epub 2014/07/22.
6. Cardella JF, Fox PS, Lawler JB. Interventional radiologic placement of peripherally inserted central catheters. *Journal of vascular and interventional radiology : JVIR*. 1993;4(5):653-60. Epub 1993/09/01.
7. Lelkes V, Kumar A, Shukla PA, Contractor S, Rutan T. Analysis of the Sherlock II tip location system for inserting peripherally inserted central venous catheters. *Clinical imaging*. 2013;37(5):917-21. Epub 2013/07/23.
8. Pittiruti M, Scoppettuolo G, La Greca A, Emoli A, Brutti A, Migliorini I, et al. The EKG Method for Positioning the Tip of PICCs: Results from Two Preliminary Studies. *The Journal of the Association for Vascular Access*.13(4):179-86.
9. Storm ES, Miller DL, Hoover LJ, Georgia JD, Bivens T. Radiation doses from venous access procedures. *Radiology*. 2006;238(3):1044-50. Epub 2006/01/21.
10. La Greca A. Evaluation Techniques of the PICC Tip Placement. In: Sandrucci S, Mussa B, editors. *Peripherally Inserted Central Venous Catheters*: Springer Milan; 2014. p. 63-83.
11. Vesely TM. Central venous catheter tip position: a continuing controversy. *Journal of vascular and interventional radiology : JVIR*. 2003;14(5):527-34. Epub 2003/05/23.
12. Odd DE, Battin MR, Kuschel CA. Variation in identifying neonatal percutaneous central venous line position. *Journal of paediatrics and child health*. 2004;40(9-10):540-3. Epub 2004/09/16.
13. Venkatesan T, Sen N, Korula PJ, Surendrababu NR, Raj JP, John P, et al. Blind placements of peripherally inserted antecubital central catheters: initial catheter tip position in relation to carina. *British journal of anaesthesia*. 2007;98(1):83-8. Epub 2006/11/25.
14. Wirsing M, Schummer C, Neumann R, Steenbeck J, Schmidt P, Schummer W. Is traditional reading of the bedside chest radiograph appropriate to detect intraatrial central venous catheter position? *Chest*. 2008;134(3):527-33. Epub 2008/07/22.
15. Luiz RR, Szklo M. More than one statistical strategy to assess agreement of quantitative measurements may usefully be reported. *Journal of clinical epidemiology*. 2005;58(3):215-6. Epub 2005/02/19.
16. Schlesinger AE, Hernandez RJ, Zerlin JM, Marks TI, Kelsch RC. Interobserver and intraobserver variations in sonographic renal length measurements in children. *AJR American journal of roentgenology*. 1991;156(5):1029-32. Epub 1991/05/01.
17. Whitley AS, Whitley AS. *Clark's positioning in radiography*. 12th ed. / [edited by] A. Stewart Whitley ... [et al.] ed. London: Hodder Arnold; 2005.
18. Royal College of Radiologists. *Picture archiving and communication systems (PACS) and guidelines on diagnostic display devices*, Second edition. 2012.
<https://www.rcr.ac.uk/picture-archiving-and-communication-systems-pacs-and-guidelines-diagnostic-display-devices-second>

19. Sampat MP, Whitman GJ, Stephens TW, Broemeling LD, Heger NA, Bovik AC, et al. The reliability of measuring physical characteristics of spiculated masses on mammography. *The British journal of radiology*. 2006;79 Spec No 2:S134-40. Epub 2007/01/09.
20. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1(8476):307-10. Epub 1986/02/08.
21. Bland JM, Altman DG. Measuring agreement in method comparison studies. *Statistical methods in medical research*. 1999;8(2):135-60. Epub 1999/09/29.
22. McGraw KO, Wong SP. Forming inferences about some intraclass correlation coefficients. *Psychological Methods*. 1996;1:30-46.
23. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychological Bulletin* 1979, 86(2):420-428.
24. Rosner B. *Fundamentals of Biostatistics*. Belmont, CA: Duxbury Press; 2005.
25. Bharath AA. *Introductory Medical Imaging*. California, US: Morgan & Claypool; 2009.
26. Hockley SJ, Hamilton V, Young RJ, Chapman MJ, Taylor J, Creed S, et al. Efficacy of the CathRite system to guide bedside placement of peripherally inserted central venous catheters in critically ill patients: a pilot study. *Critical care and resuscitation : journal of the Australasian Academy of Critical Care Medicine*. 2007;9(3):251-5. Epub 2007/09/05.
27. Robinson JF, Robinson WA, Cohn A, Garg K, Armstrong JD, 2nd. Perforation of the great vessels during central venous line placement. *Archives of internal medicine*. 1995;155(11):1225-8. Epub 1995/06/12.
28. Fletcher SJ, Bodenham AR. Safe placement of central venous catheters: where should the tip of the catheter lie? *British journal of anaesthesia*. 2000;85(2):188-91. Epub 2000/09/19.
29. McGee WT, Ackerman BL, Rouben LR, Prasad VM, Bandi V, Mallory DL. Accurate placement of central venous catheters: a prospective, randomized, multicenter trial. *Critical care medicine*. 1993;21(8):1118-23. Epub 1993/08/01.
30. Aslamy Z, Dewald CL, Heffner JE. MRI of central venous anatomy: implications for central venous catheter insertion. *Chest*. 1998;114(3):820-6. Epub 1998/09/22.
31. Collier PE, Ryan JJ, Diamond DL. Cardiac tamponade from central venous catheters. Report of a case and review of the English literature. *Angiology*. 1984;35(9):595-600. Epub 1984/09/01.
32. Reynolds N, McCulloch AS, Pennington CR, MacFadyen RJ. Assessment of distal tip position of long-term central venous feeding catheters using transesophageal echocardiology. *JPEN Journal of parenteral and enteral nutrition*. 2001;25(1):39-41. Epub 2001/02/24.
33. Tarjan Z, Pozzi Mucelli F, Frezza F, Pozzi Mucelli R. Three-dimensional reconstructions of carotid bifurcation from CT images: evaluation of different rendering methods. *European radiology*. 1996;6(3):326-33. Epub 1996/01/01.

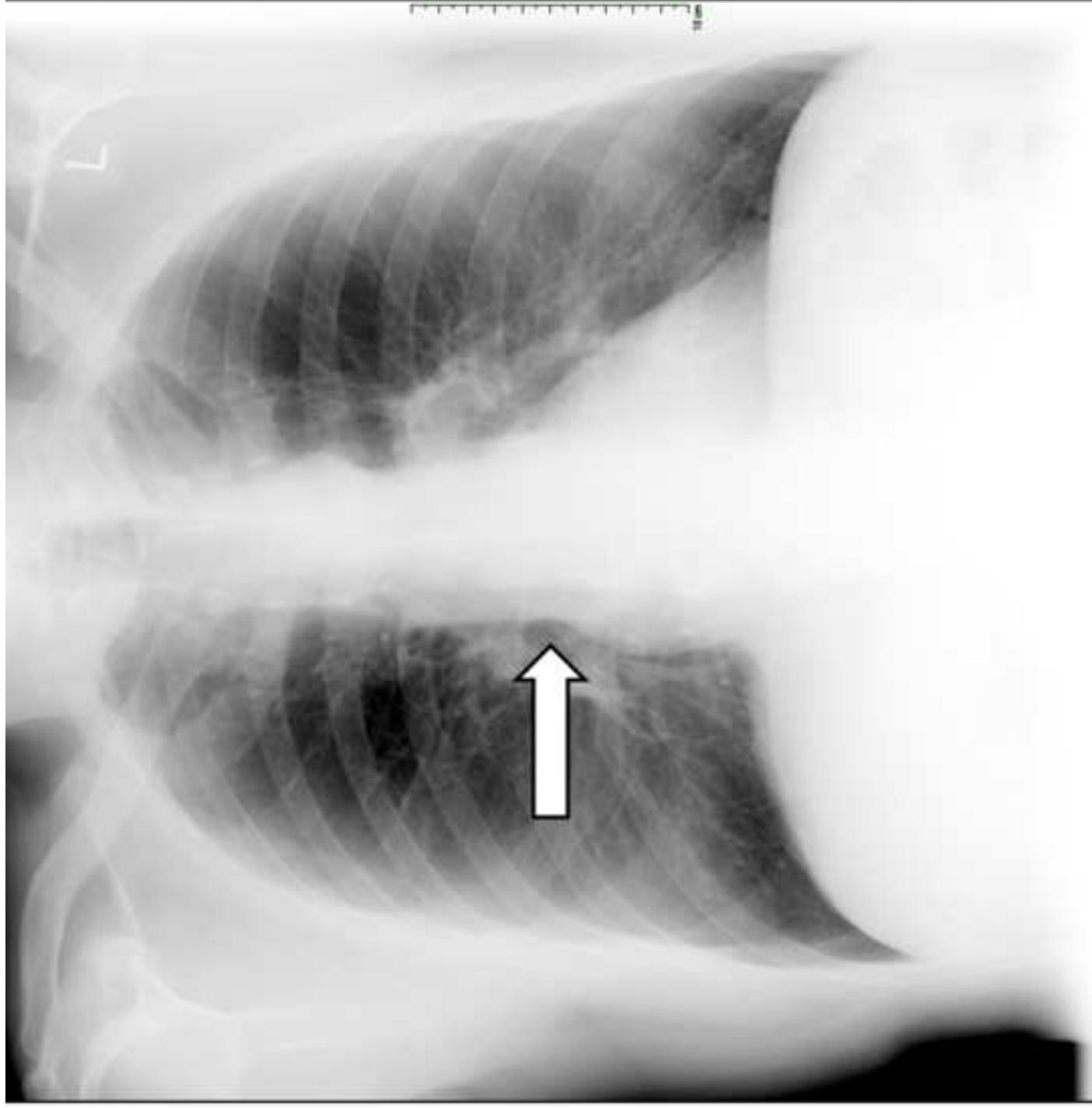


Figure 1

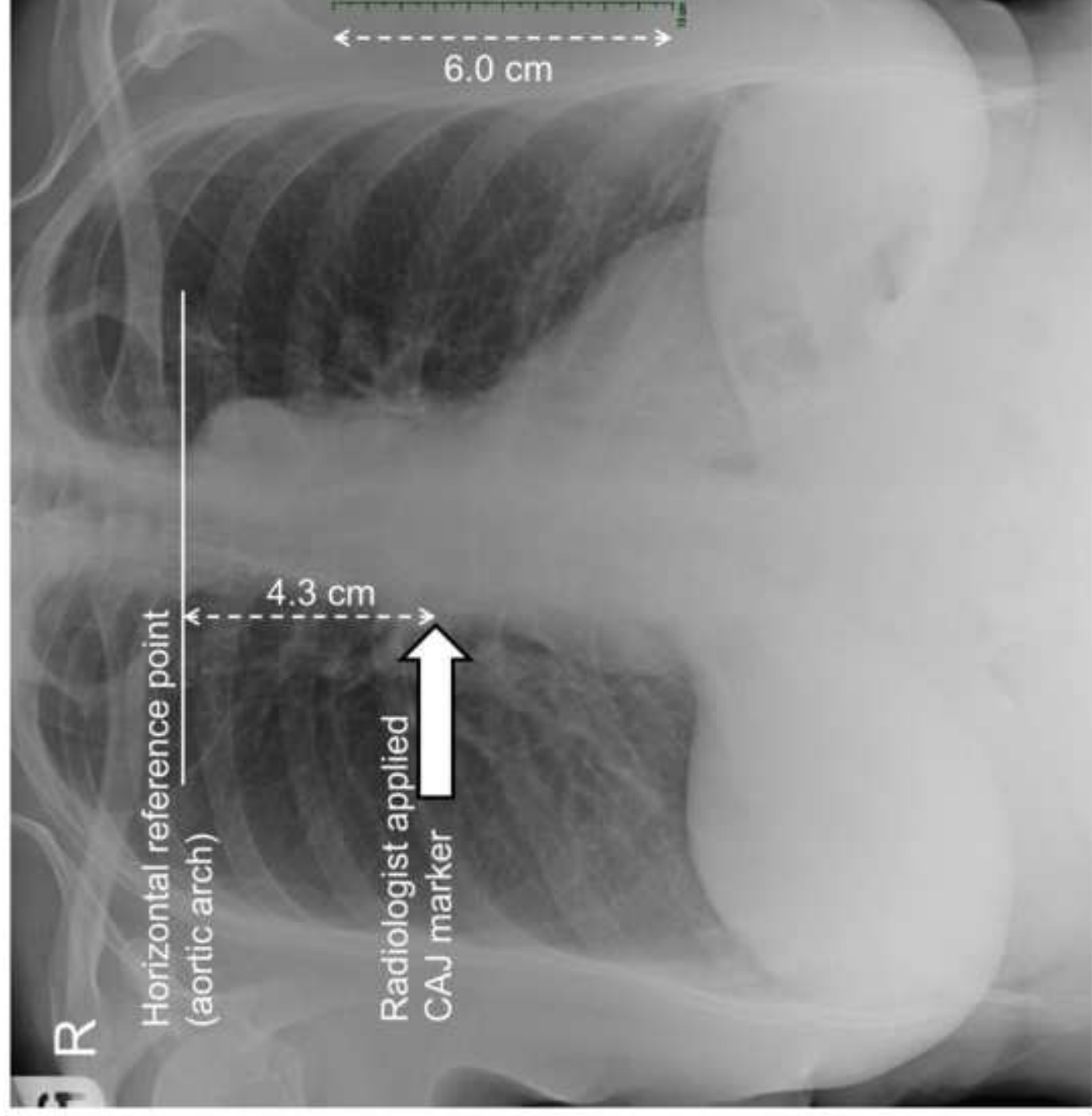


Figure 3

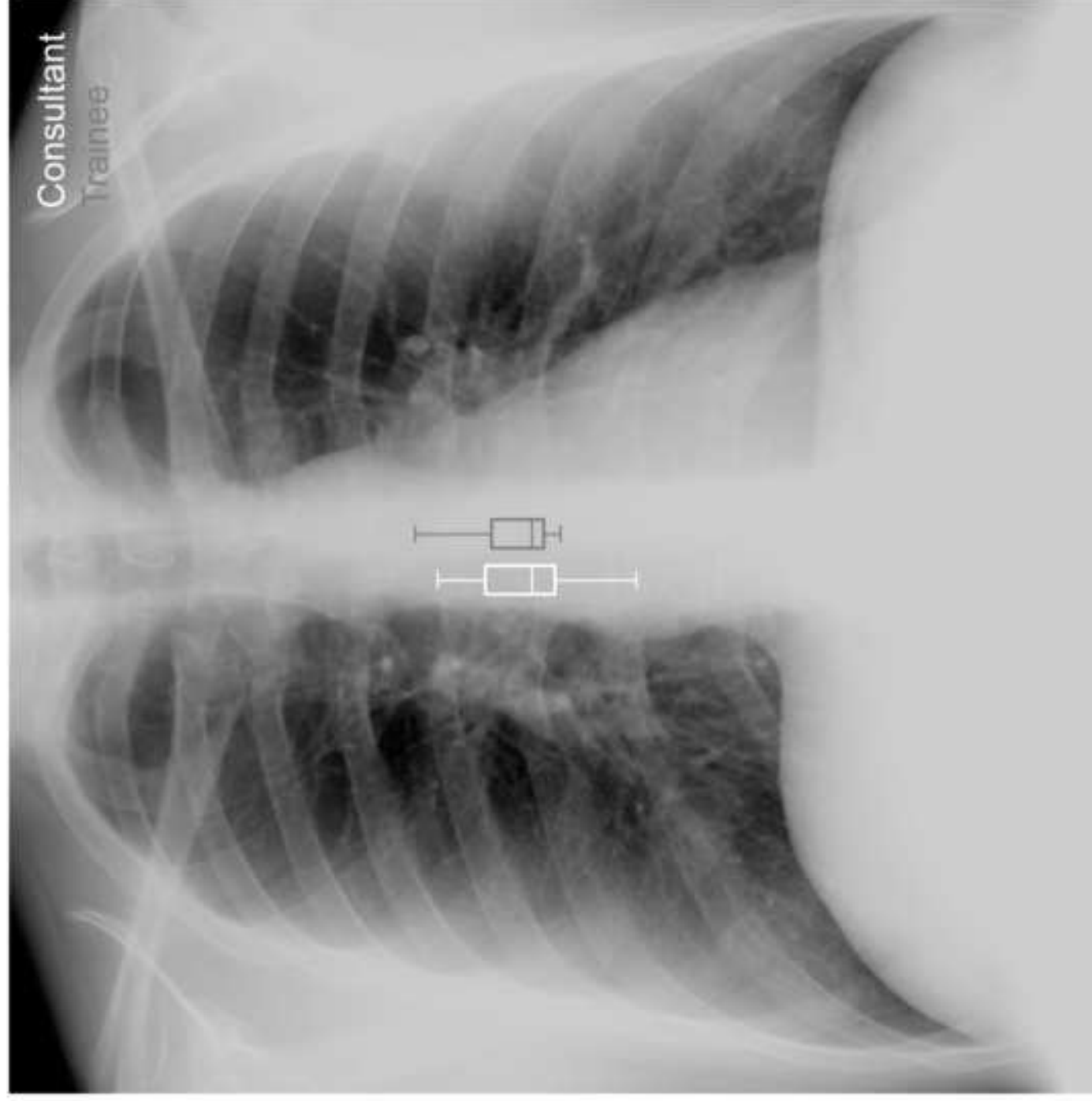


Figure 4

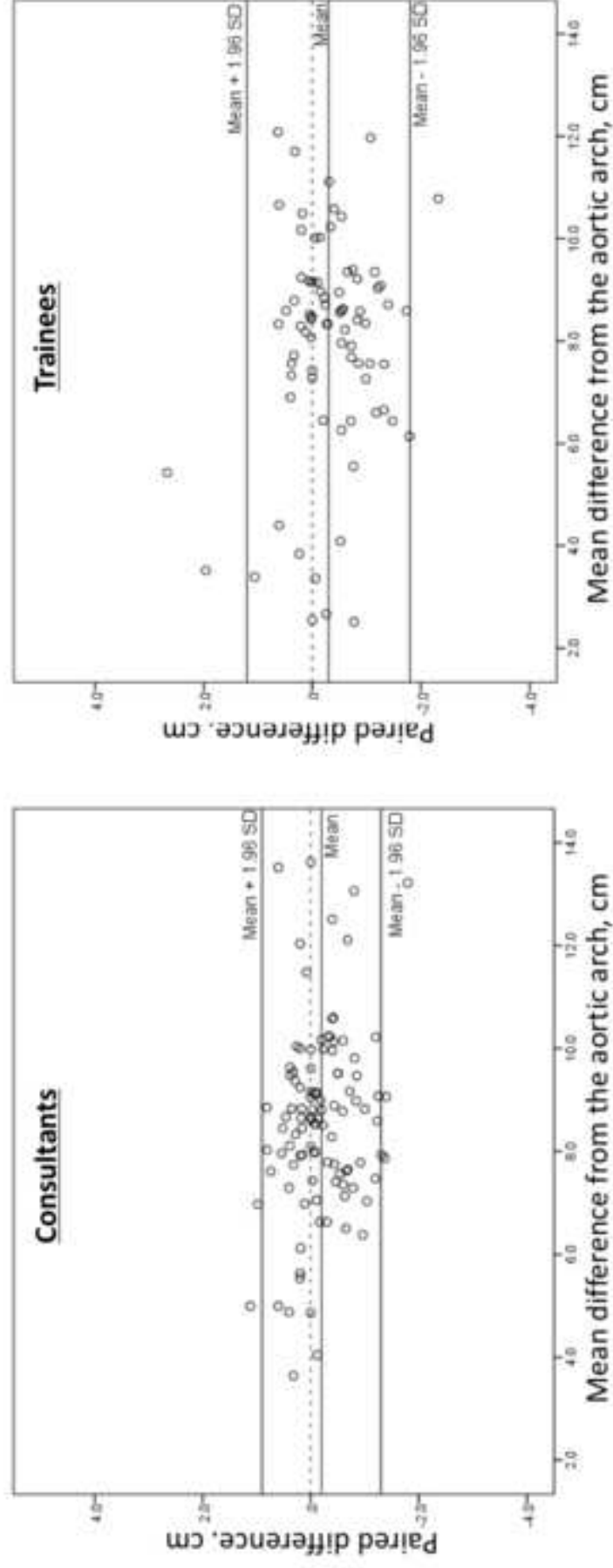


Figure 5

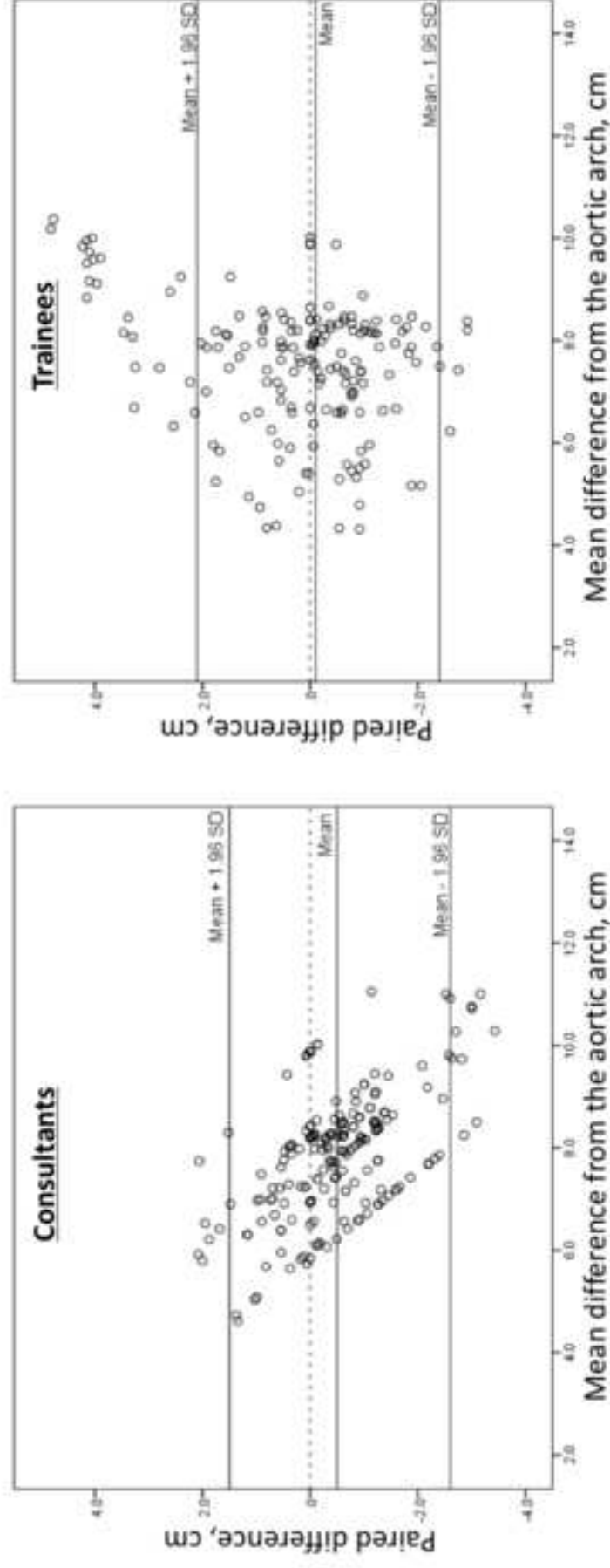


Table 1. Results for the assessment of intra-observer variability in determining CAJ position on CXR.			
	All <i>n</i> =23	Consultants <i>n</i> =13	Trainees <i>n</i> =10
n	184	104	80
Mean difference, cm	-0.2	-0.2	-0.3
SD, cm	0.7	0.6	0.8
Lower 95% LOA	-1.5	-1.3	-1.8
Upper 95% LOA	1.1	0.9	1.2
RC	1.3	1.1	1.5
> 1 cm, n (%)	26 (14%)	10 (10%)	16 (20%)
> 2 cm, n (%)	2 (1%)	0 (0%)	2 (2%)
SD, standard deviation. LOA, limits of agreement. Mean difference refers to the mean distance between the CAJ position for all of the paired CXRs. RC, Coefficient of Repeatability. n, number of paired measurements.			

Table 2. Results for the assessment of inter-observer variability in determining CAJ position on CXR.

	All <i>n</i> =23	Consultants <i>n</i> =13	Trainees <i>n</i> =10
n	374	204	170
Mean difference, cm	-0.3	-0.5	-0.1
SD, cm	1.1	1.1	1.1
Lower 95% LOA	-2.5	-2.6	-2.4
Upper 95% LOA	1.8	1.5	2.1
RC	2.2	2.1	2.2
> 1 cm, n (%)	124 (33%)	71 (35%)	53 (31%)
> 2 cm, n (%)	37 (10%)	22 (11%)	15 (9%)
SD, standard deviation. LOA, limits of agreement. RC, Coefficient of Repeatability. Mean difference refers to the differences between observer 1 measurements and the remaining observers for each of the 18 images. n, number of paired measurements.			

Table 3. Intra-class correlation coefficients (ICC).

	Within-observer				Between observers			
	n	ICC	95% CI		n	ICC	95% CI	
All	184	0.901	0.849	0.927	374	0.347	0.200	0.467
Consultants	104	0.917	0.878	0.944	204	0.355	0.151	0.511
Trainees	80	0.882	0.816	0.924	170	0.354	0.125	0.522

CI, confidence interval. n, number of paired measurements.